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Cross-Infection Risks Associated with Current Procedures for Using High-Speed Dental Handpieces

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When a dye solution used to simulate patient material was either injected into high-speed dental handpiece (drill) waterlines or applied to the equipment externally, internal air turbine chambers became contaminated. These chambers served as a reservoir of the material, which was slowly dislodged by air expelled during subsequent handpiece operation and which was diluted by water spray used for cooling the drilling surface. Considering the fact that patient materials could reside in internal parts of the equipment that are not usually disinfected and that the material may be subsequently sprayed into cuts and abrasions in the oral cavity, the common approach to reprocessing handpieces (external wiping in combination with flushing) may pose unacceptably high risks to those individuals treated soon after infected patients. Therefore, unless reliable data on cross-infection frequencies are obtained and prove it unnecessary, heat-treating high-speed handpieces between each patient should be considered an essential component of standard procedures whenever universal precautions are practiced in dentistry.

Epidemiological studies in dentistry have historically focused on practices operated by dentists infected with hepatitis B virus (HBV) or human immunodeficiency virus (HIV) (4, 9, 12, 13, 19, 24). The risk of dentist-to-patient transmission of such blood-borne diseases appears to be extremely small. Infected dentists, however, may only rarely be members of patient-to-patient cross-infection clusters; therefore, historical studies involving infected dentists cannot be used to accurately assess the extent of cross-infection problems in dentistry. Because dentistry potentially exposes much of the population to blood-to-blood contact with infected patients and because of the current lack of data on the risks of cross-infection, a careful evaluation of the likelihood that dental equipment may transmit infections is needed.

Unless adequately disinfected, a wide variety of dental equipment may pose unacceptable risks of cross-infection. Handpieces and their attachments, including prophyangles attached to slow-speed motors for cleaning and polishing teeth, and high-speed motors and their burs used for drilling are particularly prone to patient contamination. This study focuses on one potential source of infection, the high-speed handpiece, which has been referred to as the "weak link in the chain of sterility" (20). Better infection-control measures than chemical treatment alone are currently available for handpieces and their attachments to provide a greater assurance that they do not contribute to the spread of diseases. These measures include either autoclaving or dry heat treatment in conjunction with cleaning and chemical disinfection. However, achieving adequate levels of disinfection is complicated by a number of factors associated with the handpiece design. The equipment contains lumens and crevices, which collect infective patient materials and are difficult to properly clean and disinfect. Moreover, internal handpiece components are more prone to malfunction after frequent sterilization at high temperatures (29).

Autoclavable handpieces have been manufactured since the early 1980's; an American Dental Association survey in 1989 indicated that about half of the dentists practicing in the United States possessed autoclavable handpieces (28). However, even though they are widely used, the majority of general practice dentists do not autoclave them between each patient (3, 5, 11, 14, 15).

Guidelines published by the Centers for Disease Control (CDC) (Atlanta, Ga.) in 1986 suggest that an external treatment of dental handpieces with a germicide solution is an acceptable, albeit not the best, form of disinfection (23). However, studies as early as 1977 indicate that germicide treatment may not adequately disinfect the equipment (21). Additionally, some research has shown that spores inside high-speed handpieces may survive autoclaving unless the equipment is also internally treated with chemical disinfectants (8). Reliance on American Dental Association and CDC recommendations regarding chemical disinfection in lieu of heat treatment has prevailed throughout the dental profession despite the lack of data demonstrating that external disinfection is effective in controlling cross-infection. Thus, dentists have depended primarily on flushing waterlines to rid internal areas of infectious agents. This approach is supported by CDC guidelines (23), which include a recommendation for holding handpieces over a sink and running the equipment before each use in order to discharge patient materials. As a further precaution, check valves are recommended for older dental units to minimize the amount of patient material that might be retracted into waterlines and then transferred to other patients (2).

Much of the concern about the potential for dental handpieces to transmit infections has focused on pathogenic bacteria that may proliferate in waterlines (1, 2, 18, 22). As is the case with all habitable surfaces in prolonged contact with contaminated water, waterlines in and leading to high-speed dental handpieces provide an environment that is highly conducive to biofilm formation. Such attached microorganisms are unlikely to be readily flushed out and may entrap and periodically shed pathogens during high-speed handpiece operation. Viruses, on the other hand, do not reproduce outside of their hosts and therefore cannot proliferate in waterlines. Consequently, viral transmission is more

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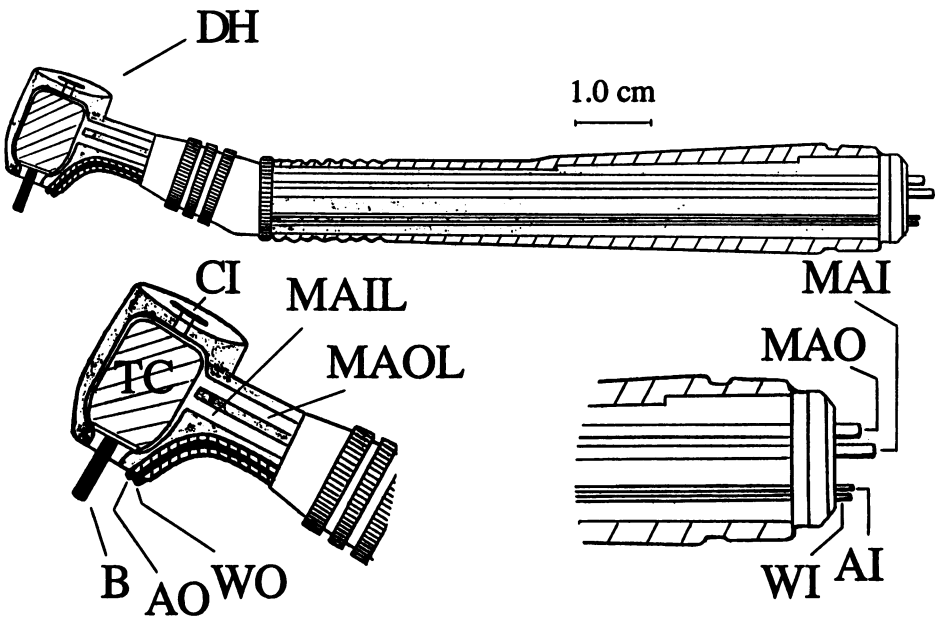

FIG. 1. Simplified diagram of a high-speed dental handpiece illustrating the chuck insert (CI) for securing the bur (B) driven by air turbines located in the turbine chamber (TC) of the drill head (DH). Turbines are turned by air entering the high-speed handpiece through the main air inlet (MAI) and entering the turbine chamber through the main air inlet line (MAIL). Air exits the chamber primarily through the main air outlet line (MAOL) to the main air outlet (MAO) of the high-speed handpiece. Some turbine air escapes through lumens around the bur and around the chuck insert. Dye was injected into the water inlet (WI) located near the air inlet (AI). Water and air exiting at the water outlet (WO) and air outlet (AO) cool the bur.

likely to be of concern when significant amounts of patient materials remain in the lumens and crevices of handpieces and of their attachments, as well as on internal mechanisms. Because many of these sites are isolated from waterlines, flushing should not be expected to rid them of contamination. Considering the nature of the various areas potentially serving as fomites, we can separate cross-infection concerns associated with dental handpieces into two distinct categories: (i) pathogenic bacterial (and possibly fungal) growth in waterlines and (ii) contamination of lumens, crevices, and airways with patient materials harboring any kinds of pathogens, including viruses.

This study specifically pertains to the latter category of problems. However, when contamination is dislodged from almost any area of a high-speed handpiece, it may be diluted as it becomes incorporated into the air-water spray used to cool the bur during drilling. Therefore, our experiments included addressing the effect of cooling water spray on contamination dilution rates.

MATERIALS AND METHODS

The amount of time required to expel contamination in waterlines was calculated by using a dye-extinction curve for approximately 0.1 ml of commercial food coloring concentrate solution (Kroger red dye, Cincinnati, Ohio). To assess contamination problems originating with waterlines, dye concentrate solution was injected with a hypodermic syringe into handpiece waterlines at the handpiece water inlet (Fig. 1). In other experiments, high-speed handpieces were exposed to the dye solution externally to simulate contamination problems associated with external surfaces of handpieces as they operate in the oral cavity. This was accomplished by switching the handpiece on and off in 1-s intervals for 25 s and contacting the bur with the surface of 50 ml of dye solution in a tilted 250-ml beaker. Care was taken not to submerge the handpiece head.

Dye was sampled in the water spray ejected from handpieces and the spray was obtained either by running the equipment continuously or by switching air and water flows on and off at 1- to 5-s intervals. Water flow rates were approximately 1.0 ml/s. Effluent samples were collected from water spray that had been expelled into glass-stoppered test tubes for up to 9 min. Sample volumes were amended with water to a total volume of 5 ml.

One-milliliter samples of the same dye solution used for treating handpieces were withdrawn with a 5-ml hypodermic syringe equipped with a 20-gauge needle. The dye solution was then partially ejected from the syringe to ensure that the needle was completely filled with dye. A silicone rubber bulb containing 5 ml of water was then punctured, and the needle was quickly withdrawn so that the contents were contaminated in a manner similar to an accidental percutaneous exposure. The needle entered the water contained in the bulb to a distance of about 0.5 cm.

Dye concentrations were measured with a Perkin-Elmer Lambda 4C Spectrophotometer at 210 nm, by using water from dental unit waterlines as reference blanks. Dilution rates were measured with a minimum of three trials each for three handpiece models manufactured by Kinetic Instruments, Inc. (Bethel, Conn.) and for three models manufactured by Midwest Dental Products Corporation (Des Plains, Ill.). Only one model manufactured by Star Dental Products (Lancaster, Pa.) was tested, and dilution rates were measured with it in three trials. Experiments were performed by using dental units both corrected and uncorrected for water retraction. Tests were not done to ensure that check valves were functioning properly at the time the experiments were conducted. Multiple trials were carried out with each handpiece to detect any dye washed out of air turbine chambers

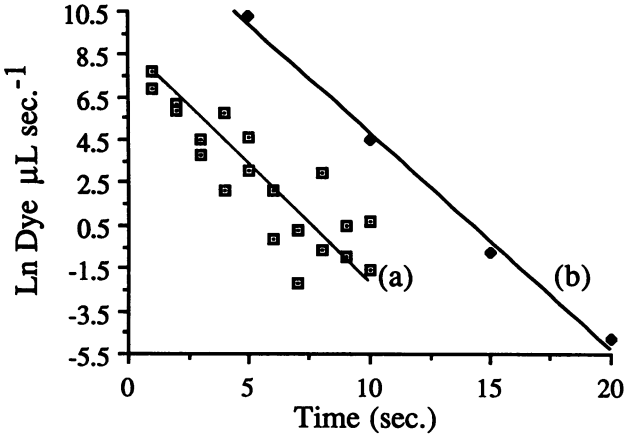

FIG. 2. Initial exponential dilution rates observed after dye was injected into handpiece waterline inlets and after effluent samples were collected as dye solution was expelled during high-speed handpiece operation. The ordinate axis is the natural logarithm of amounts of the dye solution injected into the handpiece remaining in 1-s samples of water spray expelled by the high-speed handpiece. Plots (a) and (b) represent data using handpieces from different manufacturers, and each point represents a single dye sample taken at time t.

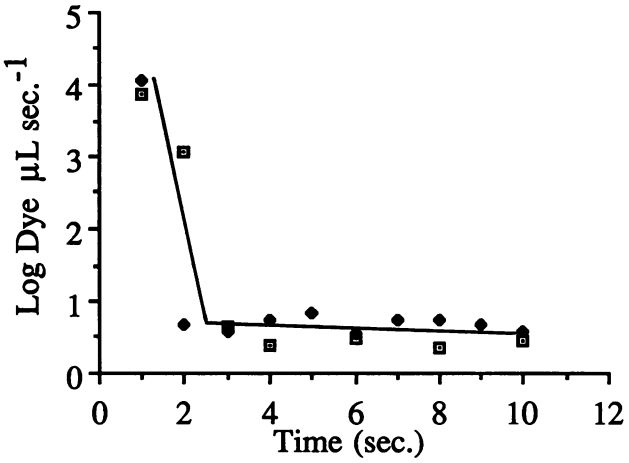

FIG. 3. Slow-elimination dilution rates observed after dye was injected into handpiece waterline inlets and after effluent samples were collected as dye solution was expelled during high-speed handpiece operation. The ordinate axis is the logarithm of amounts of the dye concentrate remaining in 1-s samples of water spray expelled by the high-speed handpiece. Solid and hollow symbols indicate duplicate trials using the same handpiece, and each point represents a single dye sample taken at time t. Means ± SD for the slow-elimination rates were 4.4 ± 1.5 (◆) and 3.4 ± 1.1 (⊡) µl s^{-1}.

after the equipment was disconnected and cleaned. Because the amounts of dye collected in air turbine chambers could invariably be easily seen with the unaided eye when the chambers were flushed, no effort was made to determine its concentrations spectrophotometrically.

Dye dilution data were plotted on logarithmic plots to illustrate that the dilution rates were exponential. Because it was not usually possible to perform replicate trials using even the same handpiece such that starting levels of dye contamination were the same in different trials, data from separate dilution trials could not be averaged and presented in the same figure. Also, so that any slight differences observed in dilution rates among different models would not be construed to imply that one model may have any significant advantage over another or that any manufacturer's equipment has advantages over another on the basis of our tests, equipment models were not identified with their corresponding data in the presentation of our results.

RESULTS

Dilution rates of dye solution injected into water inlets or applied externally to high-speed handpieces were biphasic, beginning with rapid, exponential dilution (Fig. 2). This was followed by an almost constant elimination of trace quantities of dye (Fig. 3 and 4), which originated from external surfaces and from air turbine areas contaminated by water spray. The rates of decrease in dye concentrations during the latter phase were extremely slow, which is consistent with a slow-leaking reservoir of very high dye concentrations relative to those in the expelled cooling water.

The source of dye in the slow-elimination phase was evident because dye solution could be seen collecting on exterior handpiece surfaces and coming out of the top of handpiece heads with the unaided eye. Rinsing external dye contamination from handpieces had no detectable effect on the amounts of dye expelled during the slow-elimination phase. Additionally, after disconnecting handpieces, copious quantities of dye were flushed from air turbine chambers even after the handpieces had been operated 10 min or more. Therefore, air turbine chambers were the primary source of water-spray recontamination during the slow-elimination phase. It was evident that some of the water sprayed around burs was either forced into the handpiece heads by water spray pressure or sucked into turbine chambers, perhaps when turbines rotated momentarily after the air flow was switched off. Air turbine chambers became contaminated regardless of whether the dental units were corrected with check valves to minimize water retraction and regardless of

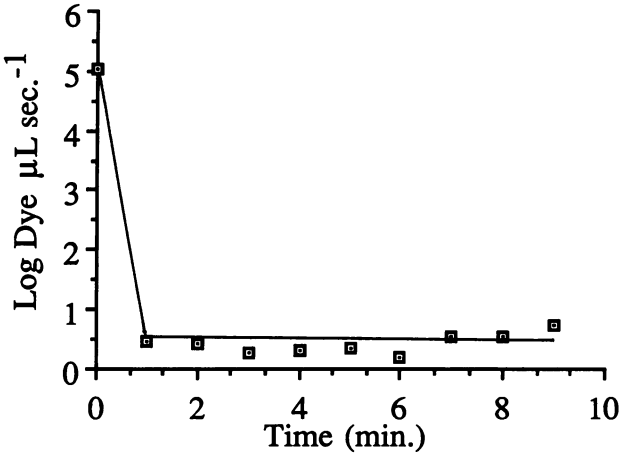

FIG. 4. Slow-elimination dilution rates obtained after a high-speed handpiece was run with the bur in contact with dye concentrate solution for 25 s and then 1-s effluent samples were collected as diluted dye solution was ejected during high-speed handpiece operation. These data are from a high-speed handpiece from a different manufacturer than for the handpiece used in Fig. 3, and it was operated for longer periods of time. Each point represents a single dye sample taken at time t. The mean ± SD for the slow-elimination rates was 2.8 ± 1.1 µl s^{-1}.

the method of dye application (injection into waterlines or external application).

By using the same dye solution used to treat handpieces, we determined that the mean amount of dye released by a 20-gauge needle per single simulated percutaneous exposure (± standard deviation [SD]) was 62.3 ± 21.9 μl (12 trials). By comparison, 2.7 ± 1.8 μl of dye per s (mean ± SD, four trials with three handpieces from two manufacturers) was expelled in handpiece water spray during the slow-elimination phase for up to 9 min when dye was either injected into handpiece waterline inlets or contacted externally (Fig. 3 and 4). When a minimum of three trials were run for each of 10 handpieces, water flushed from all air turbine chambers after the handpieces were disconnected exhibited visible amounts of dye as it washed out the handpiece air outlet. Therefore, air turbine chambers invariably became contaminated with high concentrations of dye and acted as reservoirs of contamination, which slowly leaked out during handpiece operation.

By disinfecting handpieces both internally and externally, risks of cross-infection posed by the slow-decontamination phase could be eliminated. When waterline contamination extending beyond the handpiece is not a factor, the time required to effectively flush handpieces could be based solely on contamination levels and on the initial exponential dilution rates observed with waterlines. On the basis of this approach, we calculated the time required to expel contamination suspended in waterlines by using the slopes of natural logarithmic dye-extinction plots. Because the initial dilution rates were reasonably exponential ($r^2 = 0.89 \pm 0.16$ [mean ± SD] for handpieces from three manufacturers), exponential rate coefficients, k_1, were calculated using the equation $k_1 = [\ln (C)/(C_0)]/t$, where C is the dye concentration expelled by the handpiece at time t and C_0 is the initial dye concentration in discharged water. Values of k_1 for the handpieces were $1.9 \pm 1.6\ s^{-1}$ (mean ± SD) and ranged from -0.89 to $-3.8\ s^{-1}$ for handpieces from three manufacturers. With the following equation, k_1 values could be used to calculate the time required to reduce the concentration of contamination by one half ($t_{0.5}$): $t_{0.5} = 0.693/k_1$.

The time that must be exceeded to flush a waterline of freely suspended material (X_t) could be determined using the following equation: $X_t = \ln [(B_t)/(B_0)]/k_1$, where B_0 is the initial concentration of the contaminant and B_t is one cell divided by the total volume of water contained in the line. If, for example, 0.05 ml of fluid containing 50 cells/ml was retracted into the volume of water contained in the handpiece (0.094 ml), it would require 1.03 s to flush the handpiece (determined on the basis of a k_1 value of $0.89\ s^{-1}$).

To illustrate the importance of using an appropriate dilution rate expression, we determined the amount of time required to flush the handpiece when exponential dilution is disregarded. This was calculated as the volume of water contained in the handpiece (0.094 ml) divided by the water flow rate (1.1 ml/s), which equaled 0.085 s. Consequently, it took 12 times longer to effectively flush the level of contamination in the above example than was expected solely on the basis of the water flow rate and the volume of water it contained. This difference seems insignificant, yet the time required to flush a line under exponential dilution is greatly influenced by the value of B_0. If, for example, the dentist drilled into a pocket of bacterial infection and the short waterline inside the handpiece became contaminated to a level of 10,000 cells per ml, it would take over 90 times longer to flush the line than would be expected from the water flow rate and the volume of water. Extrapolating this relationship to a 3-m length of waterline in which this high level of contamination may occur through continual retraction or bacterial growth, it would take over 3 min to completely flush the suspended contamination from the equipment.

DISCUSSION

The mathematical model we presented for predicting dilution rates is applicable to all situations, except when particulates adhere to surfaces and are not freely expelled with fluid. Both slow elimination of contamination from handpiece heads and biofilm growth could greatly extend the time required to completely rid handpieces of suspended debris. However, the mathematical model shows that several minutes of flushing is sufficient for removing even very high concentrations of freely suspended materials when the source of contamination is confined to the handpiece, although the material was not removed nearly so rapidly as one might expect solely on the basis of water flows and volumes.

Previous studies with dye and bacterial suspensions by Crawford and Broderius (6, 7) did not detect recontamination of the handpiece water spray by air turbine chambers. However, the researchers did not flush the air turbine chambers to detect contamination in that particular area, and their method of elucidating the presence of dye in waterlines (placing approximately 0.5 ml of water on white paper) would not detect the low dye concentrations measured photometrically in our samples of waterline effluent. Cases of cross-infection will often involve amounts of material not visible to the unaided eye. Therefore, fully assessing cross-infection mechanisms with dye studies requires considering even infinitesimal quantities of the dye tracer.

As in the studies by Crawford and Broderius, we have used bacterial suspensions in conjunction with dye tracers (15). We sometimes failed to detect bacteria inside equipment when liquid disinfectant was applied to the equipment externally. However, we attributed the absence of bacterial growth in samples taken from internal components of externally disinfected handpieces either to the presence of small amounts of disinfectant carried over to the growth media or to superficial disinfection of microbial aggregates by traces of disinfectants that may have entered the equipment. In any case, the difficulties involved in sterilizing microbially contaminated aggregates with liquid disinfectants are well known and provide an ample basis for an argument against assuming that nonculturability of test microbes in some experiments means that surface treatment of the equipment effectively sterilizes it internally.

Because of concentration and temperature gradients, microbial aggregates may be sterilized only on the surface by any technique designed to either sterilize or disinfect them. Additionally, the same diffusion gradients that protect aggregate interior microbes from exposure to biocidal solutions also limit their contact with nutrient solutions (16, 17). Consequently, surface-sterilized aggregates can mistakenly appear to be dead when plated on nutrient agar or suspended in a nutrient solution. However, when surface-sterilized aggregates are broken apart by a high-speed handpiece's moving parts, their viable interiors could be liberated and cause infection. Because misleading efficacy tests of disinfection or sterilization procedures could result from surface sterilization of aggregated materials, disinfection efficacy tests should always include a postdisinfection step in which aggregates in grooves and crevices of the equipment are

broken apart by sonication or by mechanical means and then tested to reveal any viable contents.

Our experiments indicated that the amount of contamination escaping handpieces per minute, for periods of time extending well beyond the brief flushing normally administered to rid the equipment of internal contamination, was equivalent to the total volume of fluid injected in multiple simulated 20-gauge-needle percutaneous exposures. For many dental procedures, such as minor restorations, risks presented by patient material-contaminated cooling water might be similar to risks involved with certain infections passed by unprotected oral intercourse; i.e., microbes either may be directly taken up through mucosal membranes or may enter small cuts and abrasions. This is not to say that the amount of microbial exposure is the same in both cases, just that the mode of infection would be the same. However, when the bur is operated invasively to the mucosa or to tooth pulp, the effect is more analogous to percutaneous exposure with a needle. Mechanical pressure applied to a syringe plunger drives fluid out of a needle and into a wound as it penetrates percutaneously. Likewise, a high-pressure flow of water directed at the cutting edge of a bur drives fluid into vascular systems as the bur cuts through mucosa or pulp. Use of a high-speed handpiece for sectioning teeth during extraction or for performing root canals is an example of such an invasive procedure. It is in such highly invasive procedures that HBV transmission in dentistry has been correlated most frequently (12, 13, 24), and most of the concern of cross-infection should be placed on them. However, with the substantial amounts of blood commonly produced even with prophylaxis treatments, the distinction between invasive and noninvasive procedures in dentistry is not so clear as it is in other fields of medicine.

In a study of 2,006 percutaneous HIV exposures among 1,962 health care workers (10), a total of six seroconversions were observed. This represents an infection rate of 0.32% per exposed person. The risk of contracting HBV, on the other hand, is within the range of 10 to 35% (10). Therefore, if the risks posed by invasive procedures with contaminated high-speed handpieces are comparable to risks of percutaneous exposures with needles, several individuals per thousand patients treated with invasive procedures soon after HIV-infected patients are treated could become infected if the equipment is not adequately disinfected between each patient. An even larger number of patients could be infected with HBV under these circumstances.

Not all of the contaminated water spray from a high-speed handpiece would be taken up internally as is the case with fluids left in needle punctures. The overall risks of infection for these two types of exposures, however, may be somewhat comparable since the spray may deliver the equivalent fluid volumes of several percutaneous exposures per minute (determined on the basis of our results) and an invasive dental procedure with a high-speed handpiece may last for 30 min or longer. Moreover, a needle prick injects material rather passively compared with a high-pressure jet of water directed into a sizable, bleeding wound where a tooth is being extracted or the pulp invaded. Admittedly, percutaneous exposure with a needle is not a perfect model for invasive drilling, perhaps not even a good enough one to reasonably state whether it over- or underestimates risks of invasive dental procedures. Nevertheless, it provides the only benchmark currently available by which we could even begin to assess the possible risks for the transmission of HIV and other diseases via invasive procedures performed with contaminated high-speed dental handpieces.

Considering the facts that material from previous patients can reside in parts of the equipment that are not usually disinfected and that the material may be subsequently sprayed into cuts and abrasions in the oral cavity, the common approach to reprocessing handpieces is inadequate. This concern is ameliorated somewhat because of the relatively low incidence of some of the infections of primary concern (HBV and HIV), which tends to make the overall risks of cross-infection for these diseases low at present. However, patient material ejected from handpieces is likely to pose unacceptably high risks to those particular individuals treated soon after infected patients, and common sense would dictate that risks posed by handpieces should be regarded no differently than other contaminated equipment, such as explorers and scalers, for which the CDC and others have recommended only heat sterilization.

These studies, along with others we cited, suggest that a significant cross-infection potential exists with high-speed handpieces whenever they are only externally disinfected. However, to date, not one case of dental equipment mediated cross-infection has been confirmed and reported in the medical literature. Either the conclusions of studies indicating the cross-infection potential have been overstated or the current system for detecting and reporting cross-infection in dentistry is largely ineffective. Indeed, there is no specific surveillance system for detecting individuals who may have contracted any disease from infected dental patients treated previously to them. Moreover, because of the current widespread assumption that HBV and HIV transmission through dentistry is extremely rare, there is little to no incentive for governmental agencies to investigate possible cross-infection clusters, especially whenever those clusters include (as they almost invariably will) individuals with one or more recognized risk factors. Additionally, because patient cross-infection clusters may only rarely include an infected dentist, historical studies involving HBV- and HIV-infected dentists cannot be expected to indicate frequencies of cross-infection. Therefore, we should consider that the current absence of reported cross-infection cases in dentistry may be due more to the lack of an adequate means of detection than to the universal application of an adequately high level of infection control throughout the profession.

Only epidemiological studies can ascertain the actual frequencies at which diseases are transmitted in practice. Appropriate cross-infection studies in dentistry could be accomplished either (i) by following the rates of seroconversions among many hundreds or thousands of patients treated shortly after infected patients or (ii) by investigating clusters of infected patients. In the latter studies, patients sharing epidemiologically linked microbial strains would conclusively represent cross-infection in cases in which the dentist is not infected and in which the patients cannot be epidemiologically linked outside the dental practice. Studies by the CDC linking HIV infections in five patients to an infected dentist in a Florida practice (25–27) represent the first time that DNA sequencing has been used to elucidate shared infections among dental patients. HIV infections are relatively rare among the population as a whole, and the rates at which the virus undergoes nucleotide sequence changes as it is passed from one patient to the next are very high. Thus, notwithstanding the fact that the HIV studies we propose would be both expensive and difficult, HIV appears to present us with an unusual opportunity to ascertain cross-infection frequencies in the practice of medicine. Unless reliable data on cross-infection frequencies are obtained and prove it unnecessary, thoroughly cleaning and heat-treating

high-speed handpieces between each patient should be considered an essential component of standard procedures whenever universal precautions are practiced in dentistry. If these steps are taken, the potential for cross-infecting patients with high-speed handpieces will be essentially eliminated.

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